View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Kanazawa University Repository for Academic Resources

Statellite monitoring of atmospheric aerosol in fine spatial resolution over Noetheast Asia

著者	Kim Young Joon, Lee Kwon Ho, Hong Chun-Sang, Hoyningen-House Wolfgang von
journal or publication title	第3回 金沢大学21世紀COEシンポジウム「環日本海域の環境計測と長期・短期変動予測」，環日本海環境戦略機構会議，国際ワークショップ「環日本海域の大気環境計測:ネットワーク形成に向けて」，COE若手研究助成金等研究成果発表会 ： 論文要旨集
page range	44-47
year	2005-02-28
URL	http://hdl.handle.net/2297/5604

Satellite Monitoring of Atmospheric Aerosol in Fine Spatial Resolution Over Northeast Asia

Young Joon Kim†, Kwon Ho Lee, Chun Sang Hong
Advanced Environmental Monitoring Research Center (ADEMRC)
Dept. of Environmental Science & Engineering, Gwangju Institute of Science & Technology (GIST), Gwangju, Korea

Wolfgang von Hoyningen-Huene
Institute of Environmental physics, University of Bremen, Bremen, Germany

Abstract

Satellite observation of atmospheric aerosol properties has become an important component of future assessments of aerosol climate impacts. Basically, satellite remote sensed data are affected mainly by the scattering effects of atmospheric molecules and aerosols in the visible band. This work discussed mainly about the retrieval of AOT from SeaWiFS and MODIS data to estimate aerosol optical parameters in fine spatial resolution over Northeast Asia. Dust plumes are often clearly seen in satellite imagery. Long-range transport of Asian dust to the Korean peninsular has also been documented. It has also been estimated that retrieval of Asian dust aerosol information from satellites showed the transport of dust plumes, as well as plumes of aerosol extending downwind from sources in this study. Aerosol parameters retrieved from SeaWiFS and MODIS data by using the BAER technique showed promising results to monitor atmospheric aerosol loading and estimate its optical properties. Additional capabilities, new retrieval methods, and observations for validation efforts are needed for the future research.

1. Introduction

Atmospheric aerosols interact with sunlight and affect the global radiation balance, causing climate change through direct and indirect radiative effects. It is known that atmospheric aerosols affect climate not only directly (*Charson et al.*, 1991) by scattering and absorbing visible and infrared energy, but also indirectly by modifying the properties of clouds and lifetime (*Twomey*, 1991). Especially, Asian continent is one of the most important sources for aerosols.

Since the lifetime of atmospheric aerosols is from few days to few months, their spatio-temporal distribution is highly variable. Satellite remote sensing technique has advantage of being capable of measuring optical and physical aerosol parameters over a large area. Satellite remote sensing can also provide the spatial and spectral resolution necessary to monitor the highly variable aerosol pattern. However, aerosol properties can be retrieved from satellite data only for cloud-free scenes. In that case, the radiance received by a satellite at the top of the atmosphere (TOA) is composed of contributions due to scattering by gases and aerosols and reflection from the surface. Hence the signal received by an electro-optical sensor on a satellite in principle contains information about the surface properties and atmospheric constituents.

Various mathematical retrieval algorithms have been used to separate them out (*King et al.*, 1999). Until recently retrieval of aerosol properties from satellite data was only possible over dark surfaces, such as oceans with very low reflectivity. Over the oceans aerosol optical thickness (AOT) has been retrieved for the past two decades, thus providing a long time record of observation data. The AOT over the ocean with measurements from the Advance Very High Resolution Radiometer (AVHRR) (*Rao et al.* 1989, *Ignatov et al.* 1995) is a representative product for aerosol retrieval. However, new retrieval techniques utilizing the features of modern satellite sensors now allow for the accurate retrieval of aerosol properties over brighter surfaces, such as the aerosol index (AI) provided by Total Ozone Mapping Spectrometer (TOMS) data (*Herman et al.*, 1997), Moderate Resolution Imaging Spectroradiometer (MODIS) retrieved aerosol products (*Kaufman et al.*, 1997a, 1997b), and The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) retrieved AOT (*von Hoyningen-Huene et al.*, 2003; *Lee et al.*, 2004a, 2004b).

Most common Asian dust and biomass-burning aerosol observed in the Northeast Asia in spring can cause visibility degradation and adverse health effects. Asian dust plume could be several kilometers in depth and hundred kilometers wide. Moreover, it can increase the albedo over the Earth surface and attenuate solar irradiance by strong scattering in short wavelength region. Biomass burning produces a complex mixture of aerosol particles including soot, soluble organic compounds, sulphates, and nitrates. Due to the high soot content, these aerosols can absorb solar radiation significantly. The absorption of solar radiation can also heat the atmosphere and alter the cloud formation.

Recently, it has become evident by estimates from satellite remote sensing data that biomass burning play an important role in regional air quality and atmospheric chemistry. Wildfire affects about 12-15 million Ha of closed boreal forest annually, most of it in Eurasia. Extensive fire activities occurred across the border in Russia, particularly east of Lake Baikal between the Amur and Lena rivers in May 2003. Biomass burning releases large amounts of particulates and gases into the atmosphere, resulting in adverse effects on regional air quality and the global budgets of radiation. Smoke pollution from the Russian forest fires was transported to Northeast Asia.

In this study, the results of AOT maps using MODIS and SeaWiFS data are presented. To retrieve AOT over the ocean and land, a look-up table constructed from the 6S (Second Simulation of the Satellite Signal in the Solar Spectrum) code with a biomass burning aerosol model was used.

2. Methodology

Table 1. shows the dataset used in this study. The SeaWiFS instrument onboard the SeaStar satellite was launched on August 1, 1998. In this study SeaWiFS Level-1A (L1A) LAC (Local Area Coverage) products, which are the radiance counts measured by a sensor, from High Resolution Picture Transmission (HRPT) stations were used for aerosol retrieval over Northeast Asia for Asian dust day case, 20 March 2001. SeaWiFS has eight bands; six in the visible (412, 443, 490, 510, 555, and 670nm) and two in the

†Corresponding author: Dept. of Environmental Science & Engineering, Gwangju Institute of Science & Technology, 1 Oryongdong Bukgu, Gwangju 500-712, Korea. E-mail: yjkim@gist.ac.kr.

Table 1. Characteristics of satellite sensors for this study.

Sensor	Bands	Swath
MODIS	36(0.41~14.2 ㎛)	2330km
SeaWiFS	8(0.41~0.86 ㎛)	2800km

near infrared wavelengths (765 and 865nm) with the tilt mechanism to avoid sun glitter (*Hooker et al.*, 1992). The spatial resolution of SeaWiFS LAC data is approximately 1 x 1 ㎢ at nadir with a swath width of 2800 ㎞. The MODIS instrument has 36 spectral bands between 0.405 □ and 14.385 □ with three different spatial resolutions; 250m, 500m, and 1000m. In this study the 1×1 ㎢ resolution Level 1 radiance data from MODIS were also used to calculate the AOD of the smoke plume using the Bremen Aerosol Retrieval (BARE) method (*von Hoyningen-Huene et al.*, 2003). Figure 1 shows a logical flow chart explaining the AOT retrieval method based on satellite data.

The TOA reflectance can be affected by many factors including solar and observation geometry, Rayleigh and aerosol scattering, atmospheric transmittance, and surface reflectance, and etc. Therefore, in order to separate aerosol reflectance from TOA reflectance, other contributors such as Rayleigh scattering and surface reflectance should be removed from it.

Since the upwelling radiance at the top of the atmosphere (TOA) over dark surfaces increases with increasing AOT, there exists a relationship between TOA radiance and AOT (*Durkee et al.* 1986). In our algorithm, unitless reflectance instead of radiance was used. TOA reflectance ρ_{TOA} is defined as;

$$\rho_{TOA}=\frac{\pi L}{E_0\cos\theta}\quad , \qquad (1)$$

where, L is the measured TOA radiance of the satellite, E_0 is the extraterrestrial solar irradiance, and θ_0 is the solar zenith angle. Aerosol reflectance ρ_a can be expressed as (*von Hoyningen-Huene et al.* 2003);

$$\rho_a=\rho_{TOA}-\rho_{Ray}(\lambda,\theta,p(z),M_0,M_S)-\omega_0(\lambda)\cdot\tau(\lambda,M_S)\cdot\rho_{Surf}(\lambda,z_0,z_S), \qquad (2)$$

where, $\rho_{Ray}(\lambda,\theta,p,M_0,M_S)$ is the normalized Rayleigh path reflectance inclusive multiple scattering for the scattering angle θ, the pressure p, the air mass factor for illumination M_0 and satellite M_S, $\omega_0(\lambda)$ is the aerosol single scattering albedo, τ is the total transmission for zenith distance of satellite z_S from sun z_0, and $\rho_{Surf}(\lambda,z_0,z_S)$ is the surface reflectance for sun and satellite geometry given by $\rho_{Surf}(\lambda,z_0,z_S)=\rho_{Surf}(\lambda)\cdot\cos(z_0)\cdot\cos(z_S)$. To calculate height dependent Rayleigh scattering, the pressure $p(z)$ at elevation z(km) was calculated by using the parameterized barometric equation defined as;

$$p(z)=p_0\cdot\exp\left[\frac{-29.87\cdot g\cdot 0.75\cdot z}{8.315\cdot(T_{surf}-g\cdot 0.75\cdot z)}\right], \qquad (3)$$

where, g is the gravity acceleration (9.807 m/s^2), z is altitude above sea level in km, T_{SURF} is surface temperature which was assumed as 298° K.

To separate Rayleigh path reflectance from TOA reflectance over the surface, the digital elevation model (DEM) was used in each pixel. The DEM used in this study is the Global 30 arc second elevation data (GTOPO30) from U.S. Geological Survey (USGS). The height z km of each pixel from DEM was used to

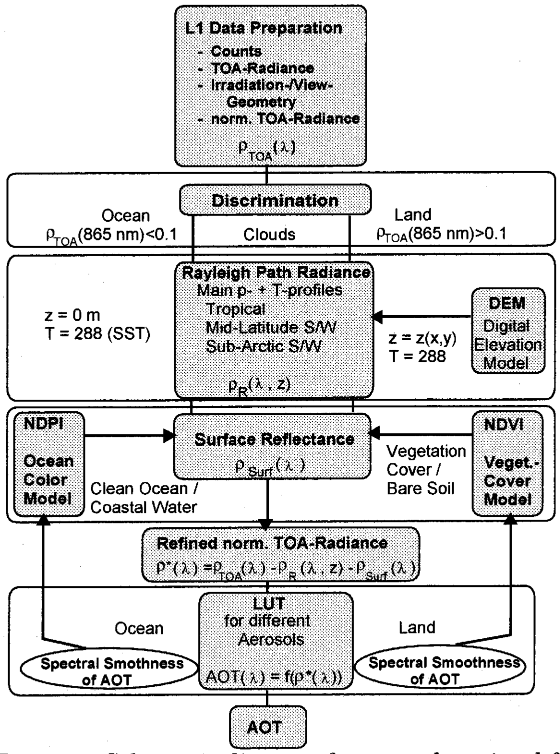

Figure 1: Schematic diagram for aerosol retrieval from satellite data

calculate the pressure determined by the parameterized barometric equation. Then the Rayleigh path reflectance can be determined with this pressure at each wavelength in each pixel.

In case of separation of the surface reflectance from TOA reflectance over land, the BAER algorithm contains the separation of the restriction on 'dark target' (*Kaufman et al.*, 1997a, 1997b). The land surface reflectance was determined by a linear mixing model of the spectral reflection of 'green vegetation' and 'bare soil'. The Normalized Differential Vegetation Index (NDVI) was used to estimate green vegetation cover from the aerosol corrected reflectance of the channels 6 (670nm) and 8 (865nm). *von Hoyningen-Huene et al* (2003) showed that the determination of surface reflectance by using the NDVI is useful tool for aerosol retrieval over land surface.

Then the surface reflectance (ρ_λ^{mixing}) was determined by linear mixing model with NDVI. as;

$$\rho_\lambda^{mixing}=NDVI\cdot\rho_\lambda^{veg}+(1-NDVI)\cdot\rho_\lambda^{soil}, \qquad (4)$$

where, ρ_λ^{veg} is vegetation reflectance, ρ_λ^{soil} is bare soil reflectance.

$$\rho_\lambda^{surf}=F\cdot\rho_\lambda^{mixing}, \qquad (5)$$

where, F is a scaling factor defined as $F=\frac{\rho_{670}^{corr}}{\rho_{670}^{mixing}}$ to adapt the level of the surface reflectance to that required within the satellite scene. ρ_{670}^{corr} is satellite-based TOA reflectance determined by subtracting Rayleigh scattering and atmospheric aerosol reflectance obtained for the channel 1 (412nm) under the assumption of a black surface. The scaling factor contributes much to a stabilization of the solutions and reduces the regional variability over the land surfaces caused by different surface type. After spectral aerosol reflectance is obtained using Eq. (2) spectral AOT is then determined from LUTs.

The SeaWiFS Level 1A data from HRPT station and MODIS Level 1A data from the Korea Aerospace Research Institute (KARI) ground station were first processed to produce TOA reflectance. Then the retrieval of aerosol optical thickness is based on the LUT constructed from 6S, assuming the biomass burning aerosol model (*Vermote* et al. 1997).

3. Results

A composite AOT map was produced using SeaWiFS and MODIS L1B data. AOT was retrieved from the cloud-free pixels of the region having a spatial resolution of 1 km × 1 km. Figure 2 (a) shows MODIS RGB images and AOT on 20 March 2001 as the Asian dust plume across Korean peninsular. An investigation of the MODIS color composite image reveals that an extremely dusty area can be seen over Northeast China and Korea MODIS-retrieved AOD shows that this dusty area has a relatively high AOD (>0.8) with a maximum exceeding 1.0, indicating a higher aerosol concentration. SeaWiFS scanned same area about 46 minutes later. In Figure 2 (b), SeaWiFS AOT at UTC 0331 on 20 March 2001 show that the Asian dust storm can be recognized by the very well defined high AOT (range of 0.6 to 1.2) dust plumes moving through the Yellow Sea. The spatial distribution of aerosol plume was almost same as MODIS.

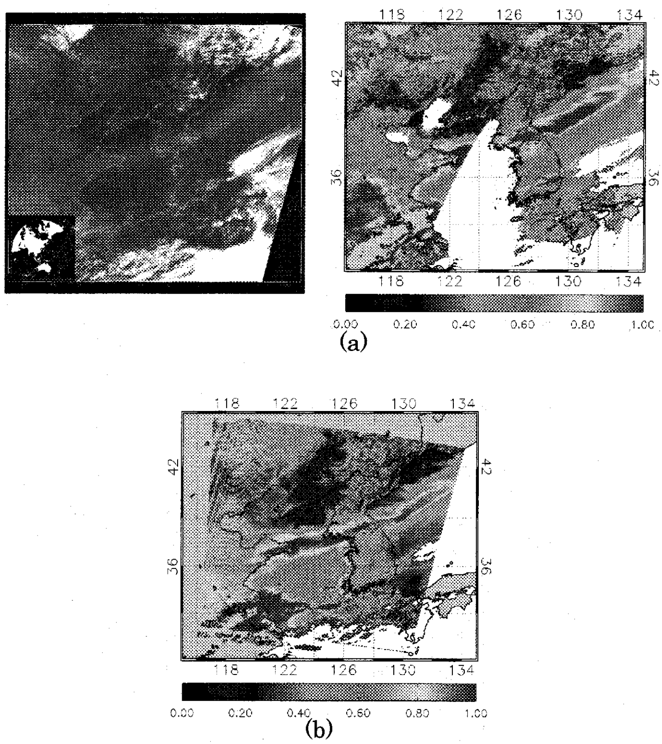

Figure 2: MODIS color composite RGB image and AOT (555nm) at UTC 0255 and SeaWiFS AOT(555nm) at UTC 0331 on 20 March 2001

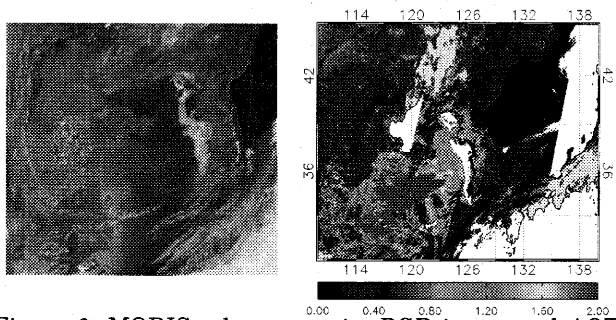

Figure 3: MODIS color composite RGB image and AOT (555nm) at UTC 0145 on 10 June 2004

Figure 3. shows MODIS RGB images with hot spots expressed as red dots and AOT over the study area. Satellite images show hundreds of hot spots in east China area. The thick smoke plume completely obscures the land and ocean surface over the study area. MODIS image also shows the severe aerosol plume that extends far to the south into Korea is transporting to the Pacific Ocean. The AOT was relatively high exceeding 1.0 over east China and Yellow Sea, indicating higher aerosol concentration.

4. Conclusion

This work discussed mainly about the retrieval of AOT from SeaWiFS and MODIS data to estimate aerosol optical parameters in fine spatial resolution over Northeast Asia. The main goals of this study were to estimate satellite-retrieved AOT using BAER algorithm over both ocean and land and estimate the spatio-temporal pattern of aerosol optical parameters from satellite data. The result of SeaWiFS and MODIS aerosol retrieval provides the regional aerosol pattern and information about aerosol optical characteristics. Satellite retrieved AOT for aerosol provides spatial distribution of aerosol to estimate the impacts of atmospheric aerosol on air quality and radiation. This results show that satellite can be capable of monitoring severe aerosol events like as Asian dust and biomass burning aerosol based on our retrieval method. Aerosol parameters retrieved from SeaWiFS and MODIS data by using the BAER technique showed promising results to monitor atmospheric aerosol loading and estimate its optical properties.

Acknowledgments

This work was supported in part by the Korea Science and Engineering Foundation (KOSEF) through the Advanced Environmental Monitoring Research Center at Gwangju Institute of Science and Technology (GIST) and the Brain Korea 21 program from the Ministry of Education.

References

Charlson, R. J., Langner, J., Rodhe, H., Leovy, C. B. and Warren, S. G., 1991: Perturbation of the northern hemisphere radiative balance by backscattering from anthropogenic sulfate aerosols. *Tellus,* 4B3: 152-163

Durkee, P. A., D. R. Jensen, E. E. Hindman, and T. H. Vonder Haar., 1986: The relationship between marine aerosols and satellite detected radiance, *J. Geophys. Res.*, 91, 4063-4072

Herman, J. R., P. K. Bhartia, 0. Torres, C. Hsu, C. Seftor, and E. Celarier, 1997: Global distribution of UV-absorbing aerosols from Nimbus 7/TOMS data. *J. Geophys. Res.*, 102, 16911-16922

Hooker, S. B., W. E. Esaias, G. C. Feldman. W. W. Gregg and C. R. McClain, 1992: An overview of SeaWiFS and Ocean Color, *NASA Techn. Mem.* 104566, Eds., NASA Goddard Space Flight Center, Greenbelt, MD, 1, 24pp

Ignatov, A. M., L. L. Stowe, S. M. Sakerin, and G. K. Korotaev, 1995: Validation of the NOAA/NESDIS satellite aerosol product over the North Atlantic in 1989. *J. Geophys. Res*, 100, D3, 5123-5132

Kaufman, Y. J., Tanré, D., Remer, L., Vermote, E. F., Chu, A., and Holben, B. N., 1997a: Operational remote sensing of tropospheric aerosol over the land from EOS-MODIS. *J. Geophys. Res, 102*(14), 17051-17068

Kaufman, Y. J., Wald, A. E., Remer, L. A., Gao, B.-C. Li, R.-R., and Flynn, L., 1997b: The MODIS 2.1-μm channel correlation with visible reflectance for use in remote sensing of aerosol, *IEEE Transactions on Geoscience and Remote Sensing*, 35:1286-1298

King, M. D., Kaufman, Y. J., Tanré, D., and Nakajima, T., 1999: Remote sensing of tropospheric aerosols from space: Past, present and future. *Bull. Am. Meterolo.* Soc., 80(11), 2229-2259

Lee, K.H., Y.J.Kim and W. von Hoyningen-Hune, 2004a: Estimation of aerosol optical thickness over northeast Asia from Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) data during the 2001 ACE-Asia intensive observation period, *J. Geophys. Res*, vol. 109, D19S16, doi:10.1029/2003JD004126

Lee, K.H., J.E.Kim, Y.J.Kim J.Kim, and W. von Hoyningen-Hune, 2004b: Impact of the smoke aerosol from Russian forest fires on the atmospheric environment over Korea during May 2003, Atmos. Environ., in press

Rao, C. R. L., E. P. McClain, L. L. Stowe, 1989: Remote Sensing of Aerosols Over Oceans From AVHRR, *Int. J. Rem. Sens.*, 10(4-5), 743-749

Twomey, S., 1991: Aerosols, Clouds and Radiation, *Atmos. Environ., 25A* (11): 2435-2442

Vermote, E., Tanre, D., Deuz, J. L., Herman, M., and Morcette, J. J., 1997, Second simulation of the satellite signal in the solar spectrum: An overview. *IEEE Transactions on Geoscience and Remote Sensing*, 35, 675-686.

von Hoyningen-Huene, W., Freitag, M., Burrows, J. B., 2003: Retrieval of aerosol optical thickness over land surfaces from top-of-atmosphere radiance, *J. Geophys. Res*. 108 (D9): 4260